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Distributed simulation for power system analysis including shipboard systems

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Abstract

Power systems are distributed in nature. Often they can be divided into sections or groups and treated separately. Terrestrial power systems are divided into separate utilities and are controlled by different regional transmission organization (RTO). Each RTO has detailed data for the area under its control, but only limited data and boundary measurements of the external network. Additionally, shipboard power systems may be divided into sections where local information is kept but not distributed to other parts of the system. Thus, performing a comprehensive power system analysis in such a case is challenging. Also, simulating a large-scale power system with detailed modeling of the components causes a heavy computational burden.

One possible way of relieving this problem is to decouple the network into subsystems and solve the subsystems respectively, and then combine the results of the subsystems to get the solution. The way to decouple the network and represent the missing part will affect the result greatly. Also, due to information distribution in the dispatch or data centers, a problem of doing power system analysis with limited available data arises. The equivalent for other networks needs to be constructed to analyze the power system.

In this paper, a distributed simulation algorithm is proposed to handle the issues above. A history of distributed simulation is briefly introduced. A generalized coupling method dealing with natural coupling is proposed. Distributed simulation models are developed and demonstrated in the virtual test bed (VTB). The models are tested with different network configurations. The test results are presented and analyzed. The performance of the distributed simulation is compared with the steady state and time domain simulation results.

Keywords: Distributed simulation; Shipboard power systems; Transient analysis; Time domain simulation; Resistive companion model; Virtual test bed (VTB)

1. Introduction

The large-scale terrestrial power systems are composed of several utilities and controlled by different regional transmission organizations (RTO). Each RTO has detailed parameters for the area under control, but only limited data of the external network. Usually, each RTO has the right to read only the boundary measurements on the tie lines that connect its control area to others. Thus, performing comprehensive power system analysis in such case is very difficult.

Also, for an all-electric ship to ensure its survivability, a weakly meshed zonal network is used. In each zone an intelligent controller coordinates the zonal connection. In the development stage, new equipment needs to be tested before the equipment is installed into the ship power system. While tests with the actual electric ship hardware are costly and risky, a virtual test environment is more affordable and safer to perform a hardware test in the prototype stage. Such hardware-in-the-loop tests can be undertaken as distributed simulation with part of the system simulated in software and part of the response originating from the hardware.

Therefore, distributed simulation, which can decouple an entire system into multiple parts, is beneficial to a large-scale power system and shipboard power systems (SPS) analysis. Distributed simulation helps provide quick diagnosis of failures in SPS and better understanding of the system status. An extension of distributed simulation could enable hardware to interact remotely [1,2].

For the reasons above, five universities in the US have teamed up for a Department of Defense Multiple University Research Initiative (MURI) project to develop remote testing and measurement (RTM) models and procedures to virtually

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connect power system laboratories over a distributed network. The MURI project targets setting up a large-scale power system laboratory to carry advanced, non-destructive testing and measurement of power systems [1].

2. Literature survey

2.1. Distributed simulation

Distributed Simulation makes use of the computer network and computes the overall power system solution through separately and concurrently computing units. One of the most developed techniques in distributed simulation is parallel processing. This method requires the information of a whole power system matrix. The advanced techniques divide the computation load based on the partitions of system matrix [3,4]. This method can greatly improve the computation speed for a large-scale power system and has been used in simulation software such as the real time digital simulator (RTDS).

The other technique in distributed simulation is based on graphically decoupling. This method is used for dc circuit analysis such as VLSI circuit analysis and large power electronic system analysis, where the dc link is selected as the coupling point [5–7]. This method is attractive when some component models are unavailable but a response of the models is available. It also conforms to the nature of the power system network, which is composed of a number of sub-networks and allows a simplified problem formulation for each sub-network.

2.2. Simulation environment

The virtual test bed (VTB) is a time domain simulation software package and provides multidisciplinary simulation environment including electrical, thermal, chemical and mechanical engineering [8,9]. Its open architecture allows users to develop their own models [8]. Its extension to real-time VTB matches the MURI final project goal of the hardware-in-the-loop test. VTB uses the resistive companion form (RCF) to model each component and get a solution through nodal analysis. RCF discretizes the device differential equations and describes the electrical component based on its instantaneous response to its terminals' voltage inputs. The independency allows the models to be developed separately and interconnect with each other easily. This technique is widely used in time domain simulation software such as Pspice, PSIM, and PSCAD [8,9].

In this work, VTB is selected as the simulation environment. However, the application of the proposed algorithm for distributed simulation is not limited to VTB. It is applicable to all time domain simulation software using RCF techniques. Remote procedure call (RPC) [10] is selected as the protocol for communication since it can invoke a function remotely through a standard interface. The functions interface called by RPC is defined by the interface definition language (IDL), which is a standard language used to describe the interface to a routine or function. RPC can further migrate to common object request broker architecture (CORBA), since objects in the CORBA are defined by an IDL. So, with simplified programming, RPC has the potential to extend to CORBA and allow for more clients and a securer connection. Therefore, these properties provide the development tools to make an application adjustable within different network environments easily and not limit the distributed simulation algorithm only within VTB.

In this paper, our research has extended the decoupling simulation method for dc link to ac systems and explored the decoupling method for a power system simulation. The algorithm's capability to deal with three-phase coupling will be demonstrated with different kinds of networks with different power sources and power load configurations. In this paper, a distributed simulation algorithm is proposed. The models dealing with the natural coupling were developed in VTB and demonstrated with different network configurations, including a shipboard power system-an 18-bus icebreaker. The distributed simulation performance is analyzed in time domain and steady state. The results, when compared to published work, demonstrate how the new models for distributed simulation expand the simulation toolbox in VTB.

3. Decoupling method

This section describes the algorithm extended from the dc coupling method to distributed simulation of power system. The problem starts with the entire power system network. Suppose that two sub-networks connect via a tie line as shown in Fig. 1. The key issues for distributed simulation include decoupling the circuit and representing the missing subsystem. The choices of the decoupling point and subsystem model will affect the stability and accuracy of the solution.

Using the VI overlap decoupling method described in paper [11], the whole system can be decoupled into two subsystems with the transmission line present in both, as the two circles indicate in Fig. 1.

When solving subsystem A, the subsystem B is treated as the "missing system." A stabilizing resistor and a current source in parallel represent the missing subsystem, subsystem B in this case, as shown in Fig. 2(a). The corresponding point in the partner subsystem B controls their values. Similarly, when solving subsystem B, the subsystem A is treated as the "missing system." A stabilizing resistor and a current source in parallel represent the missing subsystem, subsystem A in this case, as shown in Fig. 2(b).

Fig. 3 shows the general workflow of the algorithm. For detailed implementation, if the inner loop runs once, this algorithm is called a linear method. For nonlinear methods,

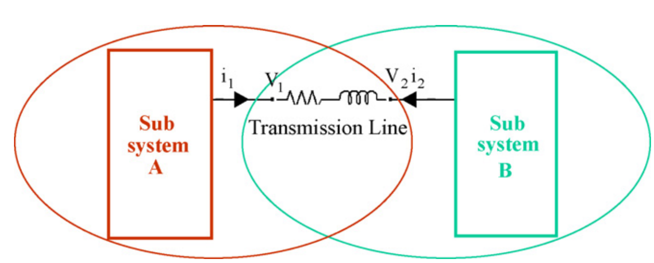

Fig. 1. Whole system without decoupling.